



## DISPERSION-SHIFTED FIBER

### BACKGROUND OF THE INVENTION

#### 1) Field of the Invention

5           The present invention relates to a dispersion-shifted fiber used as an optical transmission line in a wavelength division multiplexing (WDM) transmission system.

#### 2) Description of the Related Art

10           A WDM transmission system using an optical fiber network is capable of transmitting a large capacity of information over a long distance. The WDM transmission system typically includes a transmitter that transmits multi-wavelength optical signals, an optical fiber through which the optical signals propagates, a receiver that  
15 receives the optical signals, and an optical amplifier that amplifies the optical signals. In such a WDM transmission system, attempts have been conducted to increase the transmission capacity by broadening the wavelength bandwidth of the optical signals.

          An optical fiber intended for broadening the wavelength  
20 bandwidth has been disclosed (for example, see US Patent No. 6,282,354). The optical fiber has a zero dispersion wavelength in the range between 1575 nm and 1595 nm, a mode field diameter of 7.9  $\mu\text{m}$  to 9.1  $\mu\text{m}$ , a dispersion slope of not more than 0.10 ps/nm<sup>2</sup>/km, a cutoff wavelength of not more than 1500 nm, and a transmission loss of not  
25 more than 0.203 dB/km at the wavelength of 1550 nm. Further,

according to an embodiment of the optical fiber, the dispersion slope value is 0.07 to 0.08 ps/nm<sup>2</sup>/km (see Table 5 of US Patent No. 6,282,354).

On the other hand, the wavelength bandwidth that gives an appropriate gain in an optical fiber amplifier has been a subject of intense research in recent years. As a result, it is now possible to amplify the optical signals in a wavelength range between 1530 nm and 1625 nm. However, the optical fiber disclosed in the US Patent No. 6,282,354 is intended for optical signals in a wavelength range between 1525 nm and 1565 nm, and therefore, it is not suitable for using in a longer wavelength range between 1565 nm and 1625 nm.

#### SUMMARY OF THE INVENTION

The dispersion shifted fiber according to one aspect of the present invention has a zero dispersion wavelength that is longer than 1640 nm, a wavelength dispersion of -1.0 to -10.0 ps/nm/km in any wavelength in a wavelength range of 1530-1625 nm, a dispersion slope of a positive value less than 0.07 ps/nm<sup>2</sup>/km, a polarization mode dispersion of not more than 0.1 ps/(km)<sup>1/2</sup> at a wavelength of 1550 nm, and an effective core cross-sectional area of 40-70 μm<sup>2</sup> at the wavelength of 1550 nm.

The dispersion shifted fiber according to another aspect of the present invention has a transmission loss of 0.200 dB/km at the wavelength of 1550 nm.

The dispersion shifted fiber according to still another aspect of

the present invention has the transmission loss at the wavelength of 1383 nm that is less than the transmission loss at the wavelength of 1310 nm, and an increase in the transmission loss at the wavelength of 1383 nm prior to and after hydrogen aging is not more than 0.04 dB/km.

5           The dispersion shifted fiber according to still another aspect of the present invention has a cable cut off wavelength occurring at a length of 22 m of not more than 1300 nm.

          The dispersion shifted fiber according to still another aspect of the present invention includes a central core that surrounds an optical  
10   axis center, the central core having a first refractive index, a second core that surrounds the central core, the second core having a second refractive index, the second refractive index being less than the first refractive index, a third core that surrounds the second core, the third core having a third refractive index, the third refractive index being  
15   greater than the second refractive index, and a clad that surrounds the third core, the clad having a fourth refractive index, the fourth refractive index being less than the third refractive index.

          The dispersion shifted fiber according to still another aspect of the present invention has relative index differences of the central core,  
20   the second core and the third core with respect to the clad that are set as positive values.

#### BRIEF DESCRIPTION OF THE DRAWINGS

          Fig. 1A is a schematic diagram of a dispersion-shifted fiber  
25   according to the present invention;

Fig. 1B is a refractive index profile of the dispersion-shifted fiber; and

Fig. 2 is a graph of dispersion characteristics of the dispersion-shifted fiber.

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#### DETAILED DESCRIPTION

Exemplary embodiments of a dispersion-shifted fiber according to the present invention will be explained with reference to the accompanying drawings.

10 Fig. 1A is a schematic diagram of a dispersion-shifted fiber according to the present invention. Fig. 1B is a refractive index profile of the dispersion-shifted fiber. The dispersion-shifted fiber 1 has a center core 1a (refractive index= $n_1$ , outer diameter= $D_1$ ) that is centered on an optical axis center C. A second core 1b (refractive index= $n_2$ ,  
15 outer diameter= $D_2$ ), a third core 1c (refractive index= $n_3$ , outer diameter= $D_3$ ), and a clad 1d (refractive index= $n_4$ , outer diameter= $D_4$ ) are sequentially formed from the center around the center core 1a in a concentric manner. The refractive index of each part of the dispersion-shifted fiber 1 has been set to satisfy the relation  
20  $n_1 > n_3 > n_2 > n_4$ . In this way, the relative index differences of the center core 1a, the second core 1b, and the third core 1c with respect to the clad 1d are set to positive values. More suitably, the relative refractive index difference  $\Delta 1$  (%) of the center core 1a with respect to the clad 1d is  $0.7 \leq \Delta 1 \leq 0.9$ .

25 The dispersion-shifted fiber having such a refractive index

profile is fabricated with quartz glass as a base material, by drawing an optical preform that a dopant ( $\text{GeO}_2$ ) is dopped in a center core region, a second core region, and a third core region corresponding to the center core, the second core, and the third core and the clad,

5 respectively.

As shown in Fig. 2, the zero dispersion wavelength for the dispersion-shifted fiber 1 exists on a long wavelength side beyond 1640 nm. In the wavelength range between 1530nm and 1625 nm, the wavelength dispersion of the dispersion-shifted fiber 1 is -1.0 ps/nm/km to -10.0 ps/nm/km and the positive dispersion slope is less than 0.07 ps/nm<sup>2</sup>/km in the wavelength range between 1530 nm and 1625 nm. Further, a polarization mode dispersion of the dispersion-shifted fiber at a wavelength of 1550 nm is not more than 0.1 ps/(km)<sup>1/2</sup> and the effective area at the wavelength of 1550 nm is 40  $\mu\text{m}^2$  to 70  $\mu\text{m}^2$ . In the trial-produced dispersion-shifted fiber 1 having the structure shown in Fig. 1A, the outer diameter D1 of the center core 1a was 5.4  $\mu\text{m}$ , the outer diameter D2 of the second core 1b was 9.8  $\mu\text{m}$ , the outer diameter D3 of the third core 1c was 20  $\mu\text{m}$ , and the outer diameter D4 of the clad 1d was 125  $\mu\text{m}$ . Further, the relative index difference  $\Delta 1$  of the center core 1a was 0.82%, the relative index difference  $\Delta 2$  of the second core was 0.05%, and the relative index difference of the third core  $\Delta 3$  was 0.3%. The dispersion-shifted fiber 1 drawn from an optical preform was exposed to a deuterium containing atmosphere for about three hours.

25 The measured characteristics of the trial-produced

dispersion-shifted fiber 1 are as follows. The zero dispersion wavelength is 1664 nm, the wavelength dispersion occurring in the wavelength range between 1530 nm and 1625 nm is -2.0 ps/nm/km to -7.1 ps/nm/km, the dispersion slope is 0.056 ps/nm<sup>2</sup>/km, the polarization mode dispersion at the wavelength of 1550 nm is 0.079 ps/nm/(km)<sup>1/2</sup>, and the effective area at the wavelength of 1550 nm is 53 μm<sup>2</sup>.

The transmission losses at wavelengths of 1550 nm, 1310 nm, and 1383 nm are 0.192 dB/km, 0.37 dB/km, and 0.33 dB/km, respectively. Further, there is no increase in the transmission loss prior to and after hydrogen aging at 1383 nm. A cable cut off wavelength at a length of 22 m is 1222 nm. As a result, the dispersion-shifted fiber 1 is suitable for transmitting a large capacity of multi-wavelength optical signals ranging across a broad wavelength band between 1530 nm and 1625 nm over a long distance.

Further, the dispersion-shifted fiber 1 is suitable for a high-speed optical transmission. The deterioration of an optical signal waveform caused by a non-linear optical phenomenon could be suppressed. Further, the transmission loss due to bending could also be suppressed.

To sum up, the dispersion-shifted fiber according to the present invention is suitable for a wideband WDM transmission system.

In the present invention, hydrogen aging test in accordance with the method specified in Section C3.1, Annex C of IEC 60793-2-50 (First Edition 2002-01) is carried out. Here, the wavelength  $\lambda_y$  is taken as

1383 nm. The cable cut off wavelength at the length of 22 m corresponds to the cable cut off wavelength  $\lambda_{cc}$  specified in ITU-T (International Telecommunication Union) G.650. Other terms unless particularly defined in this document are in accordance with ITU-T

5 G.650.

Although the invention has been described with respect to a specific embodiment for a complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying all modifications and alternative constructions that may occur to one  
10 skilled in the art which fairly fall within the basic teaching herein set forth.